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Future NASA Earth-orbiting Radar Missions

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ABSTRACT

Two Earth-orbiting radar missions are planned in the near future by NASA -- Shuttle Radar Topography Mapping (SRTM) and LightSAR. The SRTM will fly aboard the shuttle using interferometric SAR (IFSAR) to provide a global digital elevation map. SRTM is jointly sponsored by NASA and the National Imagery and Mapping Agency. The LightSAR will utilize emerging technology to reduce mass and life-cycle costs for a mission to acquire SAR data for Earth Science and civilian applications and to establish commercial utility. LightSAR is sponsored by NASA and industry partners.

The use of interferometric synthetic-aperture radar (IFSAR) to measure elevation is one of the most powerful and practical applications of radar. A properly equipped spaceborne IFSAR system can produce a highly accurate global digital elevation map, including cloud-covered areas, in significantly less time and at significantly lower cost than with other systems. For accurate topography over a large area, the interferometric measurements must be performed simultaneously in physically separate receive systems. The Spaceborne Imaging Radar C (SIR-C), successfully flown twice in 1994 aboard the Space Shuttle Endeavour, offers a unique opportunity for global multifrequency elevation mapping by the year 2000. Addition of a C-band receive antenna, extended from the Shuttle bay on a mast, of approximately 60 m length, and operating in concert with the existing SIR-C antenna, produces an interferometric pair. It is estimated that the 90% Ii near absolute elevation error achievable is less that 16 meters for elevation postings of 30 meters. This will be the first use of spaceborne IFSAR to acquire accurate topographic data on a global scale.

LightSAR offers important benefits to both the science community and U.S. industry, an innovative government -industry teaming approach is being explored, with industry sharing the cost of developing LightSAR in return for commercial rights to its data and operational responsibility. LightSAR will enable mapping of surface change. LightSAR's high resolution mapping, quad-polarization, dual polarization, interferometirc and ScanSAR modes will enable continuous monitoring of natural hazards, Earth's surface deformation, surface vegetation change, and ocean mesoscale features to provide commercially viable and scientifically valuable data products.. Advanced microelectronics and lightweight materials will increase LightSAR's functionality without increasing the mass, Dual frequency L/X band designs have been examined.

Keywords: Radar, interferometry, topography, vegetation, remote sensing, SCANSAR, synthetic-aperture.

1. SRTM INTRODUCTION AND REQUIREMENTS

The SIR-C/X-SAR system is a three-frequency synthetic-aperture radar system, operating at L, C, and X bands, which was flown on two 10-day Shuttle flight.. in April 1994 and October 1994.[1,2] The L-band and C-band systems employ active distributed phased-array antennas with a high degree of agility. During these same missions, they demonstrated the ability to acquire wide-swath radar images using the SCANSAR mode of operation. SCANSAR is a radar technique that allows acquisition of a larger radar swath than would normally be possible due to range Doppler ambiguity limitations at the expense of reduced resolution. The SRTM system employs this technique with two simultaneous polarizations, each looking at a different area of the Earth at the same time. This is illustrated in Fig 1. Also, during the last three days of the previous mission, the shuttle was programmed to fly nearly identical orbits, which allowed the acquisition of interferometric radar data. The result of these repeat-pass interferometric data takes was a demonstration of the capability to generate topographic maps from Earth orbit with a radar system. Fig 2 shows a topographic map generated from two separate imaging radar passes over Long Valley, California. In this topographic map, areas of equal elevation are shown in the same intensity. The outcome of these demonstrated capabilities SCANSAR and derivation of topography for interferometry process led to the design of a radar topography mapper based on the SIR-C/X -SAR system

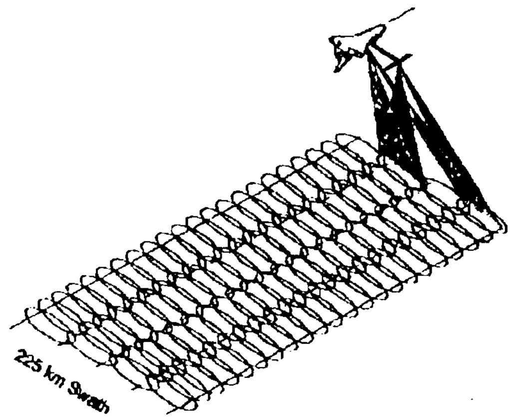


Fig. 1. Double SCANSAR data acquisition

The objective is to acquire a topographic map of as much of the Earth's surface as is feasible within the Shuttle's resources, which translates to all the land mass between the latitudes of .54°S and 60° N over a IO-day period in a 57° orbit. '1 he topographic data set produced by this mission will satisfy the requirements stated in the Defense Mapping Agency ITED-2 level. This requirement calls for a 90% vertical height accuracy of 10 m relative, over a scene, and 16 m absolute, with a posting spacing of 30 m. The Sh uttle is capable of supporting a mission of 10 days duration while providing the consumables req uired by the SIR-C system on a 57° inchoation orbit. With a 10 day repeat orbit, the required swath width for complete Ear% coverage is218 km. Due to the antenna dimensions, the only way to attain this swath width is to use SCANSAR technique% In addition, due to the accuracy requirements, both polarizations must be used simultaneously, each acquiring data from a different area on the ground in order to provide enough simultaneous looks. Over the 159 orbits of data acquisition, a total of 80 hears of data will be acquired After data acquisition, the topographic maps will be produced over a one-year interval at a data processing center at JPL.

Fig. 2. Topographic map of Long Val Icy, California, generated by SIR-C.

X.1 SIR-C/X-SAR system description

The SIR-C/X-SAR system consists of an antenna structure supporting the three antenna arrays and the SIR-C/X-SAR electronics in the payload bay. The antenna structure occupies most of the Shuttle payload bay, with the digital routing electronics and drta recorders located in the crew compartment. The SIR-C system operates at L and C bands, and each frequency uses a dual-polarized distributed phased-array antenna capable of electronic steering in both elevation (cross track) and azimuth (along track), The X-SAR operates at X-band with a single polarization and is mechanically steered in elevation. The interferometer system described uses the C-band portion of the SIR-C system, aud the description that follows will concentrate on this system. In addition to the ability to electronically steer the beam, the phased-array antenna can introduce a phase function that will spoil the beamforming of the antenna and generate a beam that is wider than the ideal antenna pattern. 'l"his is a useful feature when it is desired to illuminate a larger portion of the Earth's surface than a fully focused antenna would. 'l"he nominal system characteristics of the C-band and X-band systems for the interferometer mode arc listed in Table 1.

1.2 Interferometer requirements

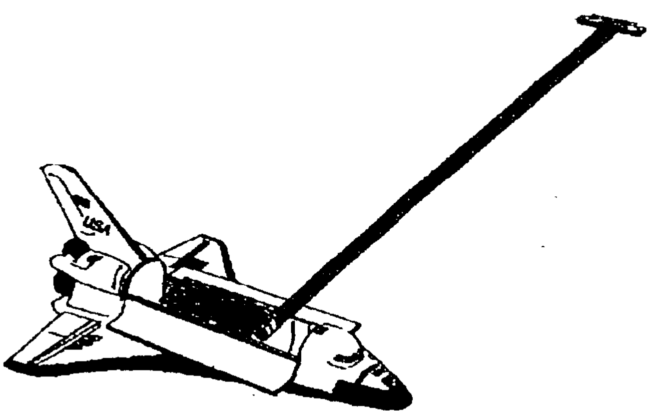
"1' he requirements for producing topographic data from an interferometer pair are well known rind documented extensively in the literature.' " In order to avoid both signal shadowing and layover, the local angle of incidence must he centered around 45°. In areas of shadow, it is not possible to unwrap the signal phase to derive local relative height, since signals arc not present In areas of layover, those areas where the local topography slope equals or exceeds the radar incidence angle, it is also not possible to unwrap the phase to derive relative elevation between picture elements The local incidence angle between the radar wave and flat terrain for the SRTM mission is Ii mited to those angles between 32° and 58°. To acquire interferometer SAK data for the SRTM mission to the required height accuracy, it is necessary to ha ve an antenna separation, or baseline, of greater than 50 m. The baseline attitude is at an angle ot'4S" from the local nadir direction and must be known to an accuracy of 11" or better. The length of the baseline must also be known to an accuracy of 2 mm or better. The baseline separation and baseline attitude must be known continuously during mapping operations, since this information is requi red by the data processor for the calculation of absolute altitude from the center of tho Earth. The Shuttle position accuracy at all times must be known within 1() m in the horizontal plane and 1 m in the vertical plane.

Table 1. SIR-C and X/SA R System Characteristics for the SRTM Mission

Parameter	Requirements	
Frequency	C-Band	X-Band
Polarization	Horizontal and vertical	Vertical
Total Swath Width	218 km	50 km
SCANSAR simultaneous beams	Two (one at each polarization)	
SCANSAR beams per polarization	Two	
Spatial Resolution	30 m	30 m
Bandwidth	10 MHz	10 MHz
System Noise Equivalent Sigma Zero	-35 dB	-33 dB
Transmit Power	1200 W per polarization	1440 W
Primary Antenna	().74 m by 12 m	0.4 m by 12 m
Secondary or Outboard Antenna	0.74 mby 8 m	0.4 m by 6 m
Baseline	62 m at a 45° angle from vertical	59 m at 52° off nadir
Transmit Pulse Duration	34 :s	40 :s
Data Rate	180 Mbps in 4 channels	90 Mbps in 2 channels
Final Product Resolution	30 by 30 m	30 by 30 m

3. SYSTEM DESCRIPTION

The SIR-C C-band system will remain nearly unchanged the previous two flights, except for some minor modifications to adapt the existing hardware to the interferometric mission, Since the interferometer will operate as a single-pass fixed-baseline instrument, a second set of receive-only antennas, onc at C-band and the other at X-band, will be added to the equipment complement. The new antennas, referred to as the Outboard Antenna Subsystem (OAS), will be mounted on an independent support structure, which will be stowed during launch and landing and deployed via au extendable mast during on-orbit operations.



Fi g. 4. SRTM interferometer configuration

Fig. 4 shows the on -orbit configuration. The sizes of the outboard antennas were chosen not only to satisfy the performance requirements of the interferometer, but also to take into account the available space within the Shuttle cargo bay. The mast, which provides the baseline separation between the main and outboard antennas, is contained in a 1.4-by-3-m cylindrical canker when stowed and deploys to 60 m when fully extended. It is au actively driven mast, composed of graphite epoxy in combination with metallic end fittings, which has the advantage of being fully rigid and mechanically stable during deployment.

The two X-baud RFEs and DCEs located under the SIR-C main antenna structure are synchronized to each other by means 01 a stable oscillator signal. A fiber-optic link will be used for signal transfer from the outboard antenna to the cargo bay. Monitoring and controlling the temperature of the LNAs and the combiner network is necessary to satisfy phase stability requirements. Two output data streams of 45 Mbit/s each arc produced, representing the raw data for the two i nterferometer images. They are multiplexed for recording on the cassette tape or downlinked at half rate.

The outboard C-band antenna array will be based on the same dual-polarized design as the main antenna. The elevation aperture is formed by 18 elements, while the azimuth aperture will be divided into 12 subapertures. Each panel will contain LNAs and phase shifters for horizontal and vertical polarization. This semiactive (receive only) configuration will provide not only the electronically steerable beam needed for SCANSAR, but it also makes more effective usc of the sensitivity of the Iow-noise amplifiers.

3.1 Metrology

The function of the metrology subsystem is threefold. The first is to measure the characteristics of the interferometer baseline to a high accuracy. The second is to calculate the position of the Shuttle, and the third is to provide the interferometer system with a precise time base to which all measurements can be related. The absolute baseline attitude is measured with a combination of sensors. The first is a star tracker mounted on an optical bench at the base of the main antenna. The star tracker provides absolute attitude updates to an inertial reference unit. A camera system, based on a star tracker, senses the relative motion of the outboard antenna with respect to the optical bench by observing three light source.s (LEDs) mounted on the outboard antenna. The absolute position of the Shuttle is measured by the GPS system, which uses an antenna mounted on tbc outboard antenna structure. The GPS system also provides the common time base. to which all measurements arc tied.

3.2 Onboard data handling and storage

The raw radar signals from four SIR -C receiver channels, two channels (HH and VV) each from primary and outboard antennas, are digitized into four 8-bit data channels, with each channel having an output rate of 45 Mbits/s. This function is performed by four Digital Data Handling Assemblies (DDHAs). The four data channels are then fed into the Digital Data Routing Electronics (DDRE). The DDRE multiplexes the data into a single IfJO-Mbit/s data stream to be recorded by one of the three Payload High-Rate Recorders (PHRRs). In addition to the above functions, the DDRE also receives X-SAR digitized data at 4S Mbits/s from the X-SAR Data and Control Electronics (DCE). The DDRE can simultaneously route any single channel of real-time or playback data to the ground via the TDRSS link. Written at 180 Mbits/s (SIR< multiplexed data rate). the digital tape cassette for the PHRR can record up to 30 minutes on a single cassette, or about 300 Gbits (about 40 Gbytes) per cassette.

3.3 Data processor and topographic map generation

After the end of the mission, the digital tapes will be first duplicated and the data tapes sent to their respective ground data processing centers, The processing procedure to generate the topographic maps is basically as follows. First, the radar data from each of the two interferometric channels is processed to generate phase maps. A difference phase map is then produced for an entire pass between ocean coastal crossings. Using the baseline angle and length information from the metrology system, a relative height map is then obtained from a phase unwrapping algorithm. The absolute height maps are then generated after calculation of the ocean heights derived from TOPEX ocean models and tide tables.

4. SRTM CONCLUSIONS

The Shuttle Radar Topography Mapper is the first mission to exploit the radar interferometry technique to acquire topographic maps on a global scale with unprecedented overall spatial resolution, height accuracy, and data uniformity. Using modified existing and flight-proven SIR-C/X-SAR hardware, the mission represents the most cost-effective means to acquire such a global map in the shortest time possible. Unlike the repeat-pass interferometry, which was tested successfully during the previous SIR-C/X-SAR mission and is currently being performed by existing spaceborne SA R systems, such as ERS 1, the fixed baseline SRTM system provides the most stable configuration for calibrated interferometry data acquisition,

5. LIGHTSAR INTRODUCTION AND REQUIREMENTS

This is a technical summary of the LightSAR system design studies performed by JPL. LightSAR is a NASA initiative to develop a low-cost Earth imaging radar satellite system that will return valuable science data, demonstrate advanced technologies, and revolutionize commercial radar imaging from space.

Because LightSAR offers important benefits to both the science and civil operations community and U.S. industry, an innovative government-industry teaming approach is being explored, with industry sharing the cost of developing LightSAR in return for commercial rights to its data and operational responsibility. The four industry teams selected to work on LightSAR defi nit-ion studies are reviewing business and teaming approaches, preparing market analyses, developing applications. defining technical approaches, and identifying potential industry cost-sharing of follow-on development. This approach is also gathering experience from previous commercial radar undertakings. [7]

The LightSAR designs presented here are non-optimized engineering solutions, formulated as a design and cost exercise, which has been examined in sufficient depth to establish confidence that it can be produced and will meet a broad set of science requirements. The LightSAR designs achieve reduced costs by matching currently available lightweight radar components with a proven commercial spacecraft bus, by using commercial launch and operations services, and by following a lean, fast-paced schedule. Conclusions from the LightSAR design exercise are: 1) LightSAR is technically feasible, and 2) LightSAR costs can be 25% that of any previous free-ftying. space-based imaging radar (including launch services).

Because of its planned long-term (3-5 yr) operation, LightSAR would collect large amounts of information about our planet, and provide an important contribution to NASA'S Mission To Planet Earth (MTPE) program and civilian environmental operational monitoring programs.' This program is a long-term research effort designed to better understand how the Earth is changing, how we cause or contribute to these changes, and how those changes affect us. In addition, the information from LightSAR could potentially help us address a range of issues.

For example, measuring motion of the Earth's surface, to help us better understand earthquakes and volcanoes and support emergency management efforts. Studying the movement.. and changing size of glaciers and ice floes to help better understand long-term climate variability. Developing highly detailed and accurate elevation maps. Monitoring floods and where they are likely to occur. Assessing terrain for the likelihood of finding oil or other natural resources. Early recognition anrt monitoring of oil spills. Assessing the health of crops and forests. Manning urban development and likely effects. Studying land cover and land use change. Because of advances in radar and spacecraft technology, the LightSAR spacecraft under study would be much smaller and less expensive and perform better than comparable systems that are in orbit.

The LightSAR satellite would provide nearly complete coverage of the Earth's surface every 8-10 days. This repeating coverage would give LightSAR the unique capability to continuously monitor changes in the Earth's topography as small as a few millimeters. Capabilities under study would enable the radar to measure features as small as 1-3 meters, offering significant potential for commercial usc in topographic mapping, land management, planning and development.

6. MISSION DESCRIPTION

LightSAR wilt generate data for commercial, Earth science, and civilian applications. LightSAR will enable mapping of surface change. LightSAR's repeat-pass interferometry technique will enable continuous monitoring 01 Earth's dynamic topography to a height accuracy of within a few millimeters. Moreover, LightSAR will have the ability to map large areas of the surface of the Earth, especially oceans, using the ScanSAR technique described in the SRTM mission To obtain both high resolution measurements for commercial interests and large scale geophysical measurements a dual frequency (L and X-band) was

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investigated as well as a single frequency ([,-band) mission Because of federal regulations restricting the bandwidth available at T,-band, resolution greater than 3 m is not realizable.

6.1. Radar Design

A parameterization of the L band and X band radar designs considered is presented in Table 2. Note that the table shows not only the frequency diversity but the polarization and operational mode diversity as well.

Table 2. **LightSAR Dual Frequency Design Comparison.**

Operational Mode	HiresX	HiresL	Repeat-pass I/F	Quad-pol	Dual-pol	ScanSAR
Frequency	X-Band	L-Band	L-Band	L-Band	L-Band	L-Band
Resolution (m)	I	3or5	40	25	25	100
Swath (km)	10	10	90	30, 60	50	280
Looks	2	1-2	8-16	3-4	8	8
Quantization	(8, 2) BFPQ	(8, 4) BFPQ	(8, 4) BFPQ	(8, 4) BFPQ	(8, 4) BFPQ	(8, 4) BFPQ
Incidence Angle	25 45"	25-45"	25-45°	20 40"	25-52°	20-52"
polarizations	HH	HH or HH + Vv	HH or VV	HH, IN, VH, VV	HH, HV or VV, VH	HH, HV
PRF (Hz)	12308-16166	2$764143	15891916	3043-3547	1986 -2(M1	1164-2000
Pulse length (ins)	15	10	15	3	10	2.8-15
Average RF power (W)	[5-1900	210-330	190-230	73-80	160-210	30.130
Data Rate (Mbps)	9-1100	98-163	72-88	101-163	93-113	21-40

Better discrimination of texture and water content will be possible and the longer (L-band) wavelength radar and use of multiple polarization modes wi II allow better distinction of texture-si, vegetation structures and water content, soil moisture, ice thickness, and other applications.

Imaging swaths of 100 km wide over will provide 25-m horizontal resolution, accurate to within a few mi llimeters vertically. As shown in '1'able 2, even higher resolution, I-3 meters, is being considered in order to provide opportunities for additional commercial applications, such as high-resolution surface mapping and co-registration with electro-optical sensor data, The wide swath (280 km) ScanSAR mode will provide large area mapping over the 500 km wide access area.

Characteristics of LightSAR design concepts under study include state-of-the-aft technologies with significant reduction in mass, as well as instrument and mission life-cycle costs. These technologies when applied to an L-band, multipolarization, high-performance SAR with multiple resolutions and swath imaging capabilities will increase the radar capability by a factor six without increasing the mass. To meet the imaging agility needs electronic beam steering has been considered to maximize the targetable swath. In addition, As noted previously X band is being considered for very high-resolution commercial applications, however. C-band also has sufficient bandwidth allocated, to meet high resolution imaging needs. Figure 5 illustrates two configurations for a **dual frequency s ystem concept.**

To make LightSAR commercially viable and to obtain time series of data over multiple seasons, designs for missions with a lifetime of 3-.5 years are being considered. The design life is important in terms of the reliability of the electronics, selective redundancy has cost implications, as well as the sizing of propellant required to maintain the orbit over the mission life. Additional electronics and propellant translate into additional mass which results in higher costs for more capable launch vehicles. Therefore, a delicate balance must be achieved between the overall system performance and the scope of requirements

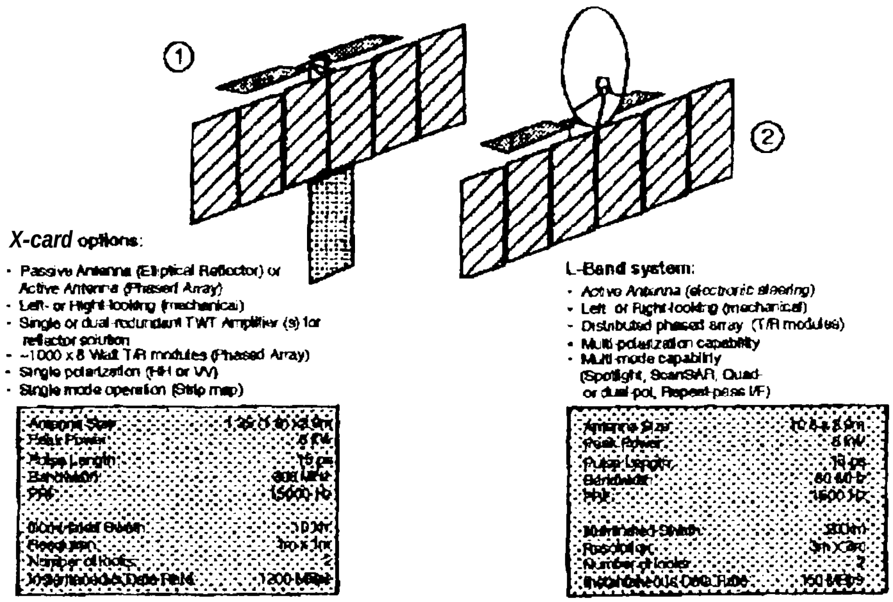

Figure 5. System configurations and designs for an L/X-band mission.

6.2. Orbit Considerations

LightSAR's 8 to 10-day repeating orbit maintained within a 250 m diameter tube (determined by the Global Positioning System, GPS), would provide visibility of most locations on Earth about once each day. the repeat period was defined to meet imagin requirements for glacier research. Flying within a 250 m tube is a significant requirement that must be met to achieve global surface deformation measurements, with accuracies of a few millimeters, using repeat pass interferometry. For design purposes a a sun-synchronous orbit at an altitude of 600 km, with an inclination of 97.8° was evaluated. Orbits at lower inclinations were also examined. Moreover, the orbit must be known with an accuracy of <10 cm radially and cross-track and 1 m along track. Commercial requirements for the orbit control and precise orbit determination are less stringent.

6.2. Spacecraft Bus

Several aerospace companies have low-cost spacecraft bus designs that could serve as the LightSAR bus. Bus adaptations required to accommodate the radar instrument(s) incl ride: attachment of the radar antenna, deployment structure, and latch mechanism; installation of radar electronics in the bus, provision for unique memory and data handling capacity, tailored downlink transmitter(s)/antenna (s), tailored solar array and battery provisions, tailored attitude control provisions and tailored GPS configuration. Figure 6 illustrates the mechanical configuration for LightSAR with an L-band radar, only. The bus configuration shown is *generic* and is used for design and cost evaluation purposes to convey one of many possible designs

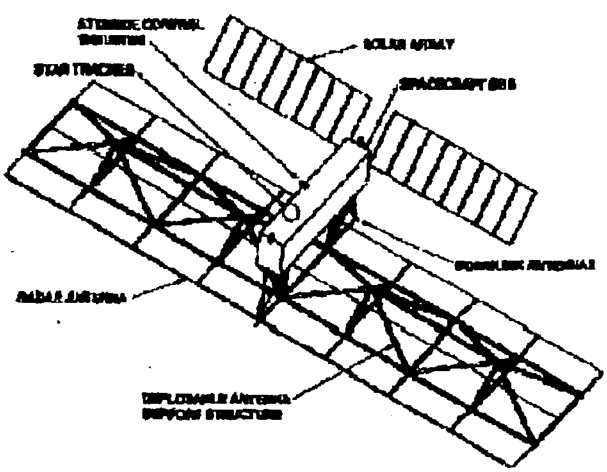

Figure 6. LightSAR Mechanical Configuration (L-band only).

Table 3 summarizes the performance needed for a bus to support an L band radar mission. The additional a second radar will require evaluation of the mechanical configuration and deployment mechanisms as well as the power demands, as shown in Table 2, for X band.

The current LightSAR design requires that the bus be capable of rolling 70° (±35° from nadir) to perform high latitude mapping near the poles (up to 80° N and 86° S). This capability also is required to provide for maximum coverage and responsiveness to commercial imaging customers.

Table 3. LightSAR Bus Performance for an L-band Radar.

Feature	Capability
Autonomy	Operate w/o commands 24 hr (typical), 7-day max
Mass	<710 kg (flight weight, without single frequency 250 kg radar
Power	50 Amp-Hr batteries; l-axis gimbaled solar array
Attitude Control	Pointing Accuracy: elevation 0.5°, azimuth 0.1"; knowledge: O.O1° Perform 70 degree roll in 10 min. (for right and left looking)
Propulsion	Maintain 250 m diam. tube about velocity vector
Data Storage	90 Gbit solid state memory, radar data recording for ~1 orbit (Spotlight mode), > 3 orbits (ScanSAR mode)
Command/Telemetry	S-band receiver/transmitter, with command encryption
Data Link	Radar: X-band transmitter, at 160 Mbps (L band radar, only)
Subsystems	Assumed design includes hot gas thrusters, reaction wheels, inertial reference unit(s), star tracker(s), sun sensors, magnetometer, and onboard Global Positioning System (GPS)

7. LIGHTSA R CONCLUSION

LightSAR is the firs NASA commercial SAR mission. An innovative NASA-Industry partnership has been established to reduce the cost of SAR mission by a factor of four while increasing the capability. This partnership will utilize advanced MIMIC devices and lightweight materials to develop high performance radar systems that will meet both NASA's science goals and Industry's commercialization goals. Not only will a new set of working relationships and technologies he applied but existing spacecraft launch vehicles and an operations infrastructure will be used to reduce costs and maintain a schedule that will bring LightSAR to orbit years sooner than was previouisly achievable.

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